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PARITY-EVEN AND PARITY-ODD MESONS IN COVARIANT LIGHT-FRONT APPROACH

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Decay constants and form factors for parity-even (s-wave) and parity-odd (p-wave) mesons are studied within a covariant light-front approach. The three universal Isgur-Wise functions for heavy-to-heavy meson transitions are obtained.

1. Introduction

Interest in even-parity charmed mesons has been revived by recent discoveries [1] of two narrow resonances: $D_{s0}^*(2317)$ and $D_{s1}(2460)$, and two broad resonances, $D_0^*(2308)$ and $D_1(2427)$. The unexpected and surprising disparity between theory and experiment has sparked a flurry of many theory papers.

Before our work,[2] the Isgur-Scora-Grinstein-Wise (ISGW) quark model[3,4] is the only model that can provide a systematical estimate of the transition of a ground-state s-wave meson to a low-lying p-wave meson. However, this model is based on the non-relativistic constituent quark picture. Since the final-state meson at the maximum recoil point $q^2 = 0$ or in heavy-to-light transitions can be highly relativistic, it is thus important to consider a relativistic approach. The covariant light-front model elaborated in [5] is suitable for this purpose, but again it has been only applied to s- to s-wave meson transitions. In [2] we have extended the covariant LF quark model to parity-even, p-wave mesons and studied their decay constants, form factors and the corresponding Isgur-Wise functions.

2. Decay constants and form factors

Consider the decay constants for mesons with the quark content $q_1\bar{q}_2$ in the ${}^{2S+1}L_J = {}^1S_0,\ {}^3P_0,\ {}^3S_1,\ {}^3P_1,\ {}^1P_1$ configurations. In the SU(N)-flavor limit ($m_1 = m_2$) the decay constants $f_{S({}^3P_0)}$ and $f_{{}^1P_1}$ should vanish.[6] In the heavy quark limit ($m_1 \to \infty$), it is more convenient to use the $L_J^j = P_2^{3/2}$, $P_1^{3/2}$, $P_1^{1/2}$ and $P_0^{1/2}$ basis as the heavy quark spin s_Q and the total angular momentum of the light antiquark j are separately good quantum numbers. Since decay constants should be identical within each multiplet, ($S_0^{1/2}$, $S_1^{1/2}$), ($P_0^{1/2}$, $P_1^{1/2}$), ($P_1^{3/2}$, $P_2^{3/2}$), heavy quark symmetry (HQS) requires [7,8]

$$f_V = f_P, \qquad f_{A^{1/2}} = f_S, \qquad f_{A^{3/2}} = 0, \tag{1}$$

where we have denoted the $P_1^{1/2}$ and $P_1^{3/2}$ states by $A^{1/2}$ and $A^{3/2}$, respectively. It is important to check if the calculated decay constants satisfy the non-trivial SU(N)-flavor and HQS relations. The numerical results are shown in Table 1.

Table 1. Mesonic decay constants (in units of MeV) obtained. Those in parentheses are taken as inputs.

${}^{2S+1}L_J$	$f_{u\bar d}$	$f_{s\bar u}$	$f_{c\bar u}$	$f_{c\bar s}$	$f_{b\bar u}$
${}^1S_0$	(131)	(160)	(200)	(230)	(180)
${}^3P_0$	0	22	86	71	112
${}^3S_1$	(216)	(210)	(220)	(230)	(180)
${}^3P_1$	(−203)	−186	−127	−121	−123
${}^1P_1$	0	11	45	38	68
$P_1^{1/2}$	–	–	130	122	140
$P_1^{3/2}$	–	–	−36	−38	−15

From Table 1 we see that the decay constants of light scalar resonances are suppressed relative to that of the pseudoscalar mesons, while the suppression becomes less effective for heavy scalar mesons. Our result of $f_{D_{s0}^*} = 71$ MeV is supported by the measurements of the $B \to D^{(*)}\bar D_{s0}^*$ decays.[1]

Form factors for heavy-to-heavy and heavy-to-light transitions have been computed in the covariant light-front approach. The details are shown in [2]. Our results for form factors in $B \to D, D^*, D^{**}$ (D^{**} denoting generic p-wave charmed mesons) transitions agree with those in the ISGW2 model.[4] Relativistic effects are mild in $B \to D$ transition, but they could be more prominent in heavy-to-light transitions, especially at maximum recoil ($q^2 = 0$). For example, we obtain $V_0^{Ba_1}(0) = 0.13$,[2] while ISGW2 gives 1.01. If $a_1(1260)$ behaves as the scalar partner of the ρ meson, it is expected that $V_0^{Ba_1} \sim A_0^{B\rho} \sim O(0.3)$. The predicted decay rates for $\overline{B} \to D^{**}\pi$ and $\overline{D}_s^{**}D^{(*)}$ obtained in the CLF model agree with experiment.[2]

It is worth mentioning that the ratio $R = \mathcal{B}(B^- \to D_2^{*0}\pi^-)/\mathcal{B}(B^- \to D_1^0\pi^-)$ is measured to be $0.80 \pm 0.07 \pm 0.16$ by BaBar [9] and 0.77 ± 0.15 by Belle.[10] The early prediction by Neubert [11] yields a value of 0.35, while soft-collinear effective theory predicts $R = 1$.[12] Our prediction of $R = 0.91$ in the covariant light-front model is in accordance with the data.

3. Heavy quark limit and Isgur-Wise functions

In the heavy quark limit, heavy quark symmetry[7] provides model-independent constraints on the decay constants and form factors. For example, pseudoscalar and vector mesons would have the same decay constants and all the heavy-to-heavy mesonic decay form factors are reduced to some universal Isgur-Wise functions. Therefore, it is important to study the heavy quark limit behavior of these physical quantities to check the consistency of calculations.

It is well known that the s-wave to s-wave meson transition in the heavy quark limit is governed by a single universal IW function $\xi(\omega)$.[7] Likewise, there exist two

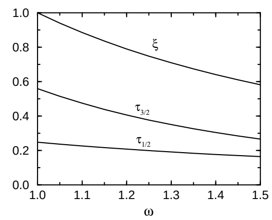

Fig. 1. The Isgur-Wise functions ξ, $\tau_{1/2}$ and $\tau_{3/2}$ as a function of ω.

universal functions $\tau_{1/2}(\omega)$ and $\tau_{3/2}(\omega)$ describing ground-state s-wave to p-wave transitions.[13] The calculated IW functions are shown in Fig. 1. It is found that at zero recoil $\omega = 1$, $\xi(1) = 1$, $\tau_{1/2}(1) = 0.61$, $\tau_{3/2}(1) = 0.31$ and $\rho^2 = 1.22$ for the slope parameter of $\xi(\omega)$. Our results for $\tau_{1/2}$ and $\tau_{3/2}$ agree well with the recent lattice results [14] $\tau_{1/2}(1) = 0.38 \pm 0.05$ and $\tau_{3/2}(1) = 0.58 \pm 0.08$. The Bjorken [15] and Uraltsev [16] sum rules for the Isgur-Wise functions are found to be fairly satisfied.

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References

1. BaBar Collaboration, B. Aubert *et al.,* Phys. Rev. Lett. **90**, 242001 (2003); hep-ex/0408041; CLEO Collaboration, D. Besson *et al.,* Phys. Rev. D **68**, 032002 (2003); Belle Collaboration, K. Abe *et al.*, Phys. Rev. D **69**, 112002 (2004); hep-ex/0307041.
2. H.Y. Cheng, C.K. Chua and C.W. Hwang, Phys. Rev. D **69**, 074025 (2004).
3. N. Isgur, D. Scora, B. Grinstein, and M.B. Wise, Phys. Rev. D **39**, 799 (1989).
4. D. Scora and N. Isgur, Phys. Rev. D **52**, 2783 (1995).
5. W. Jaus, Phys. Rev. D **60**, 054026 (1999).
6. M. Suzuki, Phys. Rev. D **47**, 1252 (1993).
7. N. Isgur and M. B. Wise, Phys. Lett. B **232**, 113 (1989); **237**, 527 (1990).
8. A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Lett. B **387**, 582 (1996).
9. BaBar Collaboration, B. Aubert *et al.,* hep-ex/0308026.
10. Belle Collaboration, K. Abe *et al.,* Phys. Rev. , D **69**, 112002 (2004).
11. M. Neubert, Phys. Lett. **B418**, 173 (1998).
12. S. Mantry, hep-ph/0405290.
13. N. Isgur and M. B. Wise, Phys. Rev. D **43**, 819 (1991).
14. D. Becirevic *et al.*, hep-lat/0406031.
15. J.D. Bjorken, SLAC-PUB-5278 (1990); J.D. Bjorken, J. Dunietz, and J. Taron, Nucl. Phys. B **371**, 111 (1992).
16. N. Uraltsev, Phys. Lett. B **501**, 86 (2001).